

# Power from Nuclear Transmutation Gen III-IV Fission Reactors (II)

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Energy: Science, Technology & Society

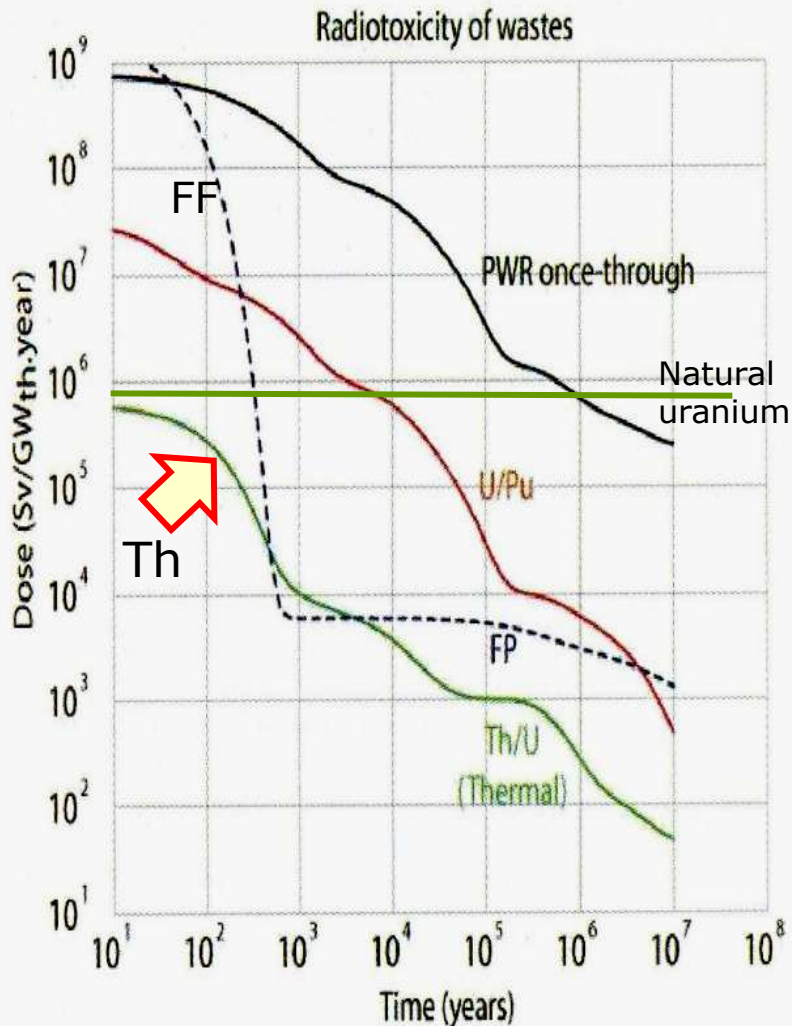
The Diablo Canyon NPPT produced CO<sub>2</sub>-free electricity at 2¢/kwh, half the state's (CA) average cost.

# Agenda

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- Nuclear stability & particle radiation  
Potential biological hazards
- Energy Generation from Nuclear Fission  
U.S./World trends,  
Nuclear fuel resources (U.S.),  
Fission chain reaction and reactor control,  
Reactor types,  
Fuel cycles, radioactive waste & storage.
- **New Nukes: Advanced Nuclear Energy Technologies**  
Small modular reactors (SMR plants),  
Advanced (Gen II+, Gen IV) reactor designs,  
U & Th breeder reactors, subcritical reactors,  
Closed fuel cycle,  
Applications: Radioisotope Thermoelectric Generators (RTG)  
Nuclear medicine
- Strategic Issues for Nuclear Power  
Sustainability, reliability, scalability, safety, eco-footprint, cost
- Energy from nuclear fusion reactions  
Fusion energetics, critical  
Principles of magnetic and inertial confinement

# Radiotoxicity of Spent Nuclear Fuel: Th vs. U



(David & Nifenecker, 2007)

Radio toxicity vs. time after shutdown, of spent fuel from

- pressurized water uranium reactor,
- U/Pu breeder, and
- Th/U fuel cycle.

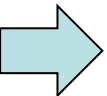
FP fast decay of fission products.  
Transactinides largely consumed in reactor operations.

Multiple reprocessing, much less residual waste than in U-cycle.

Transmute/incinerate Transactinides and FF mitigates remaining waste issue.

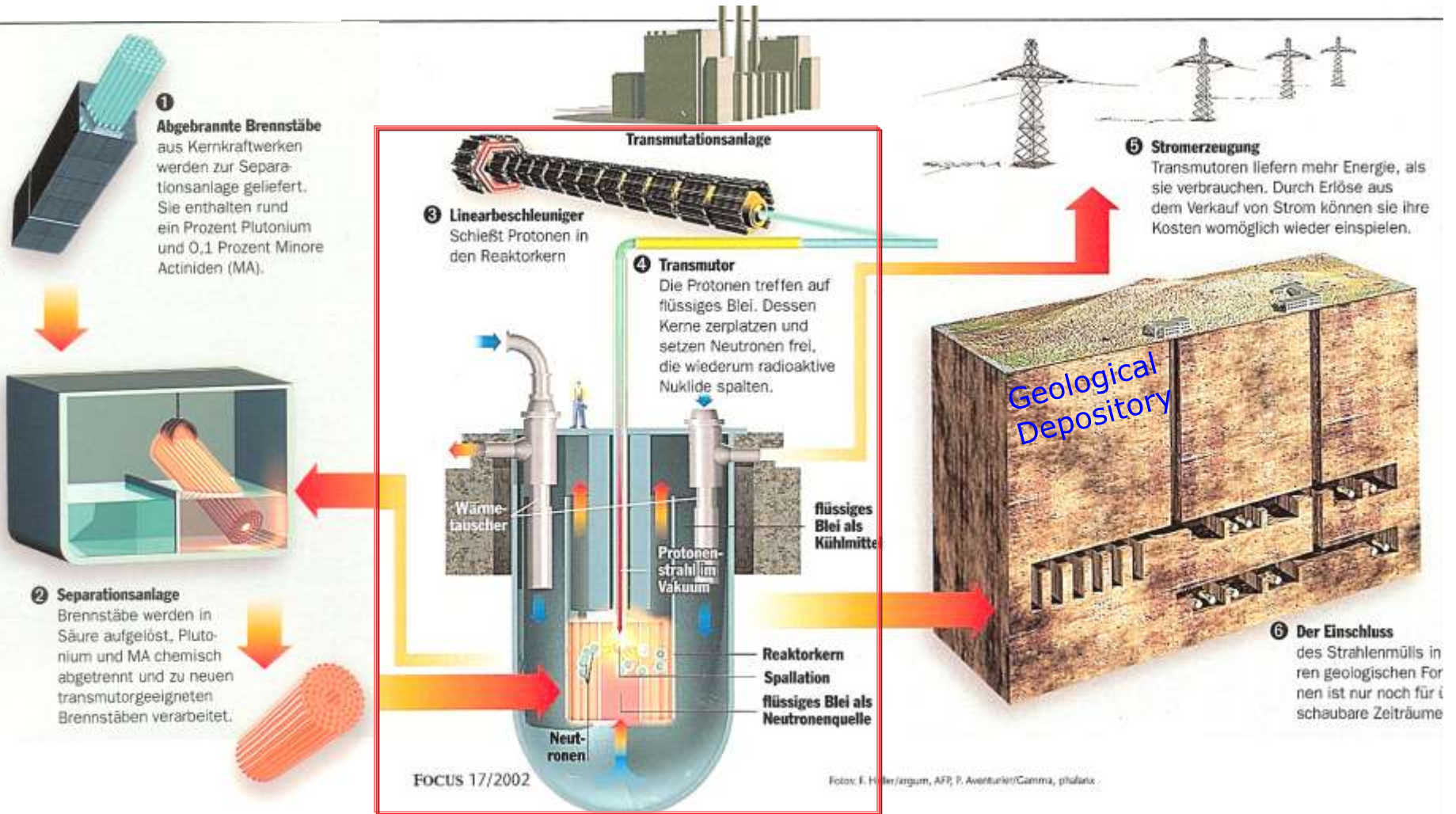
Store small amounts of HL waste for ~100 years (use for decay- $\alpha$ 's ?)  
Needs small geological depository.

Subcritical Accelerator Driven

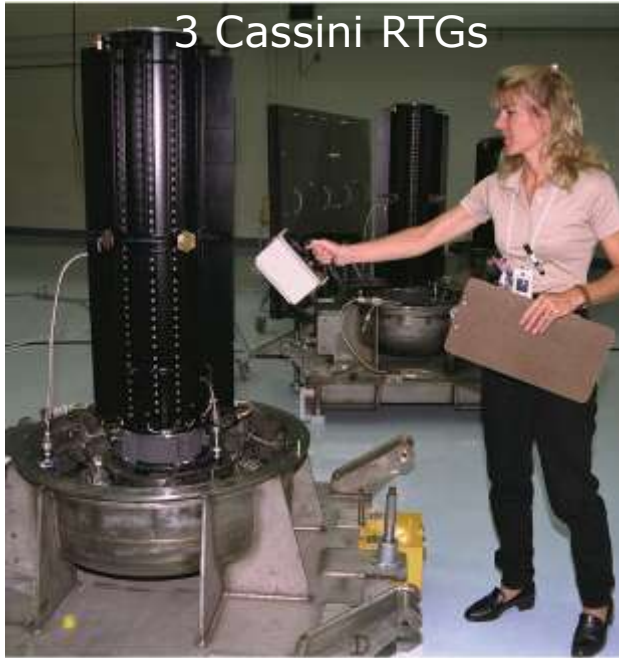


# Transmutation/Breeding in **ADS**

**Spallation:** n multiplication  $\rightarrow$  incineration of waste generates E  
Advanced (ADS) reactor development under IFNEC (GNEP) program



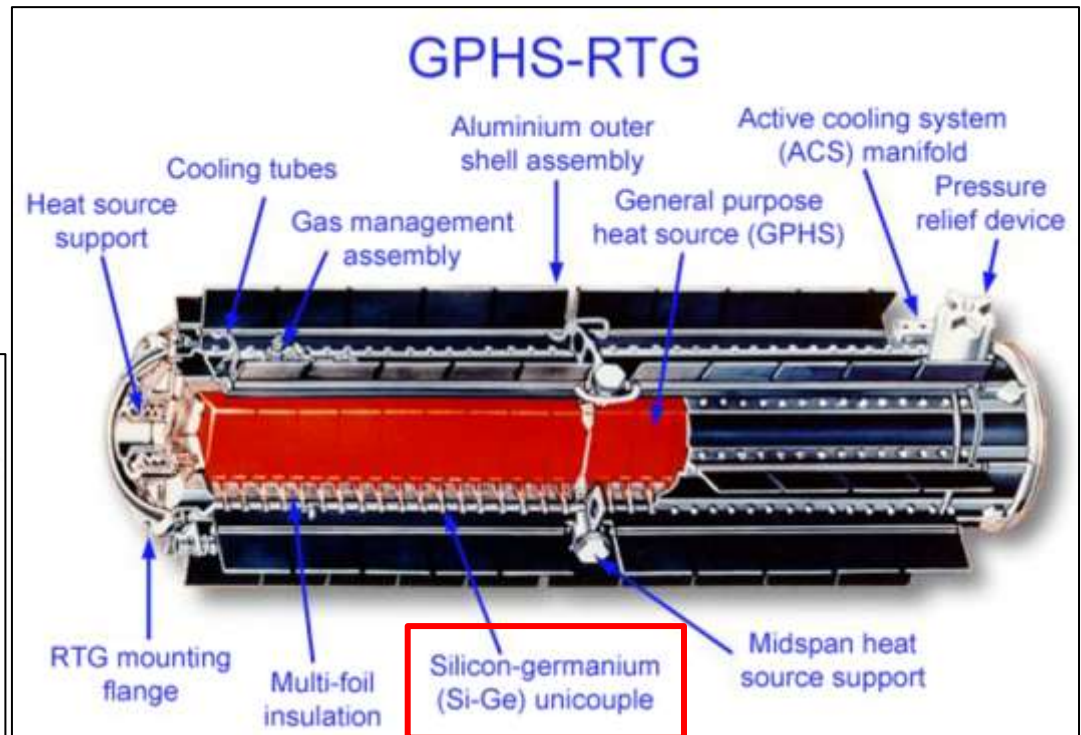
# Radioisotope Thermoelectric Generators



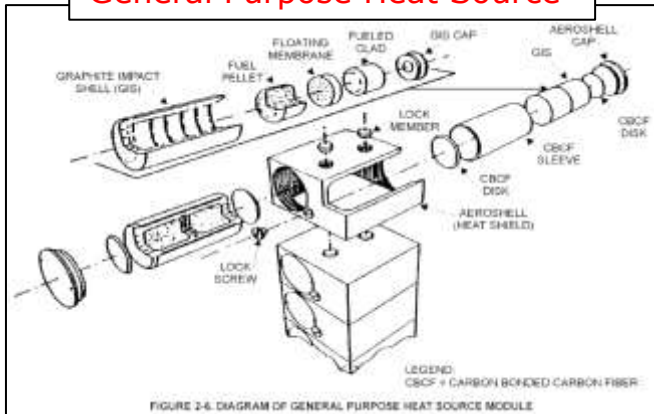
3 Cassini RTGs

**Pu-238** ( $t_{1/2} = 87.7a$ ) RTG in many NASA space applications, also for remote terrestrial instrumentation (Arctic scientific or military outposts).

Heat  $\rightarrow$  Thermocouple  $\rightarrow$  Electricity

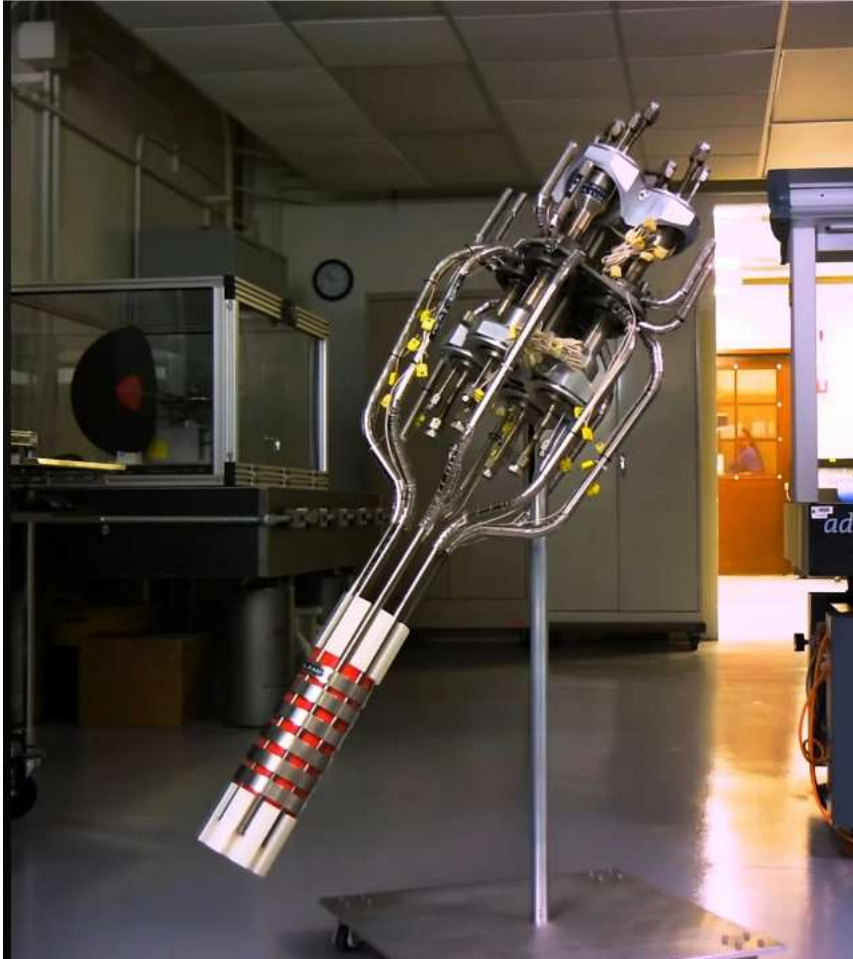


General Purpose Heat Source



# NASA Space Probe

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A NASA Pu-238 Radioisotope Thermoelectric Generator has been in use to power space probes for many decades.

Efficient combination with Stirling engine.

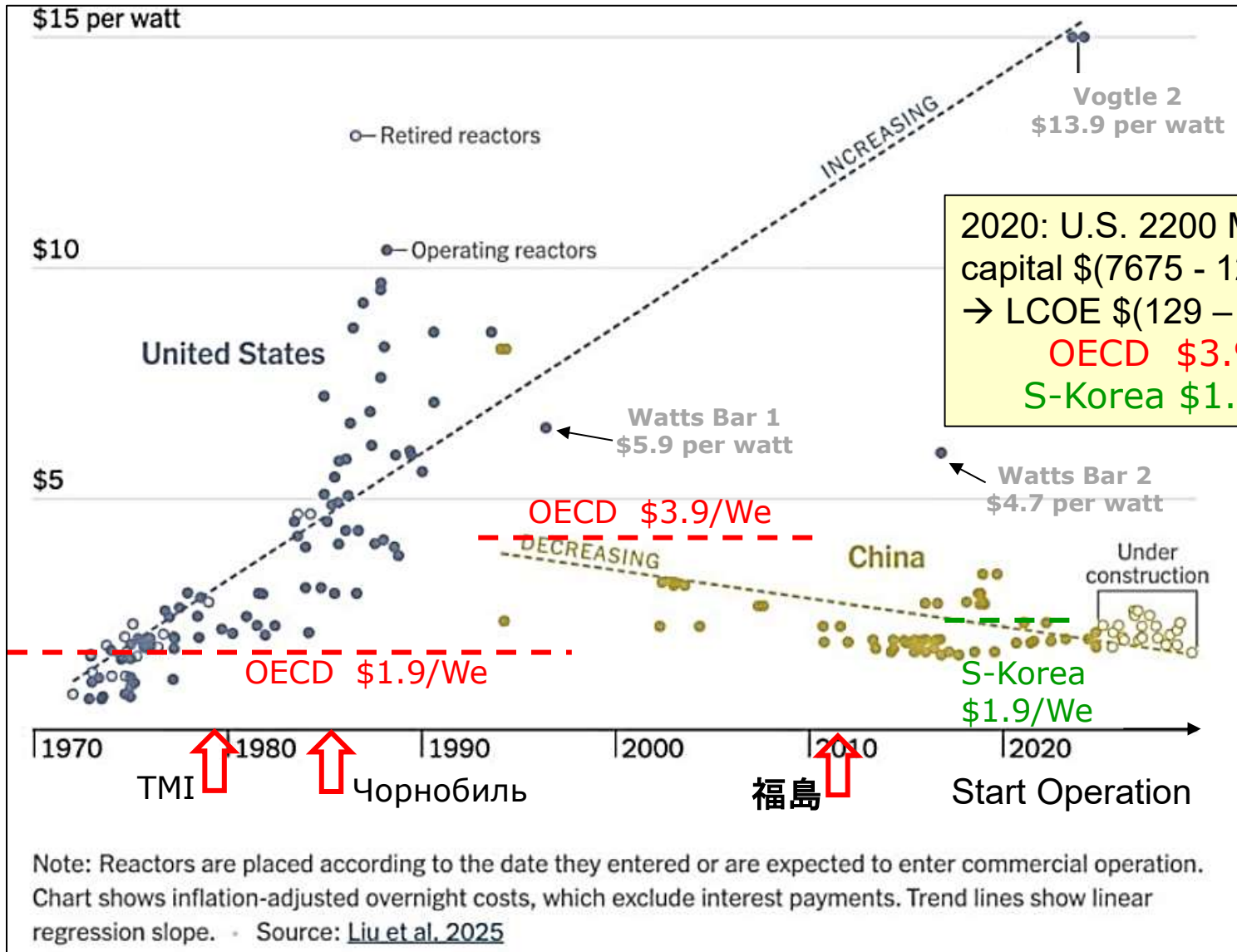
Voyager I and II, Cassini probe.

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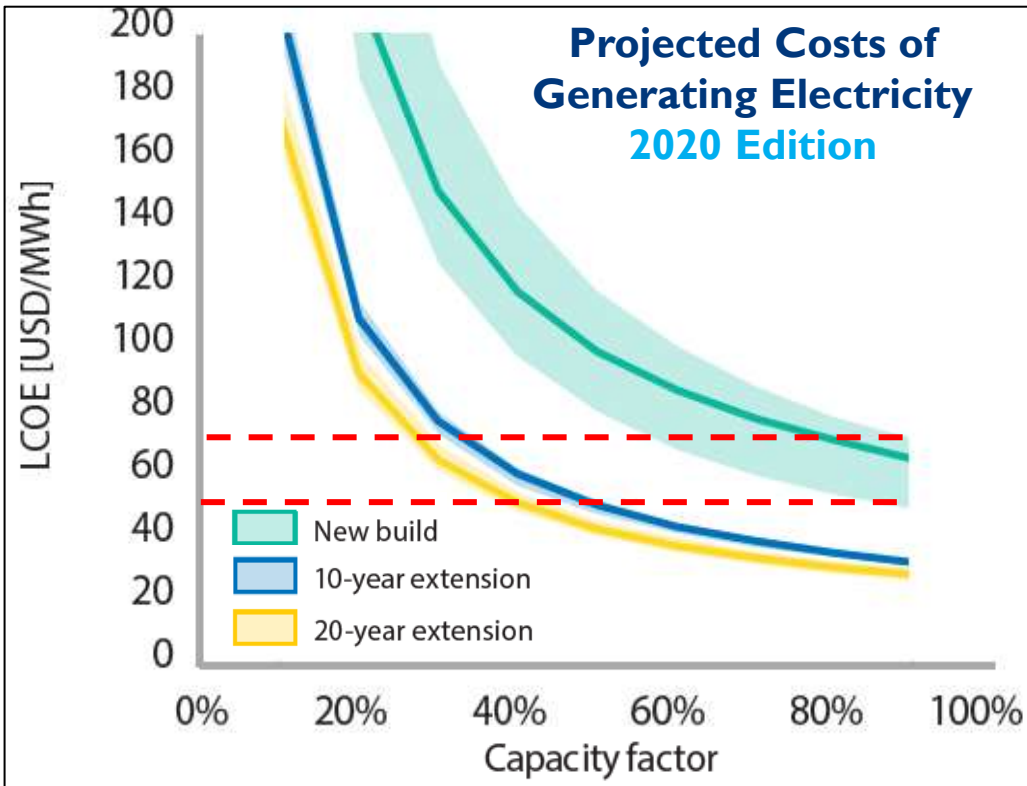
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# Nuclear Fission Reactors: Historical Construction Cost



2020: U.S. 2200 MWe plant:  
 capital \$(7675 - 12,500)/kW  
 → LCOE \$(129 - 198)/MWh.  
 OECD \$3.9/We  
 S-Korea \$1.9/We

# Cost Estimates for Nuclear Plants & Electricity



← 2020 Report IEA & NEA

U.S. EIA: 2023 (<2050) **Advanced NP** LCOE ≈ \$110/MWh

**PV** LCOE ≈ \$55/MWh (2023) → \$25/MWh (2050).

**Wind (on sh.)** LCOE ≈ \$40/MWh (2023) → \$35/MWh (2050).

Similar trends for EU, China, India

**Sugg. economic strategy:**  
 Extended Lifetime Operations (**LTO**) of existing plants, with substantial upgrades (Electrical,

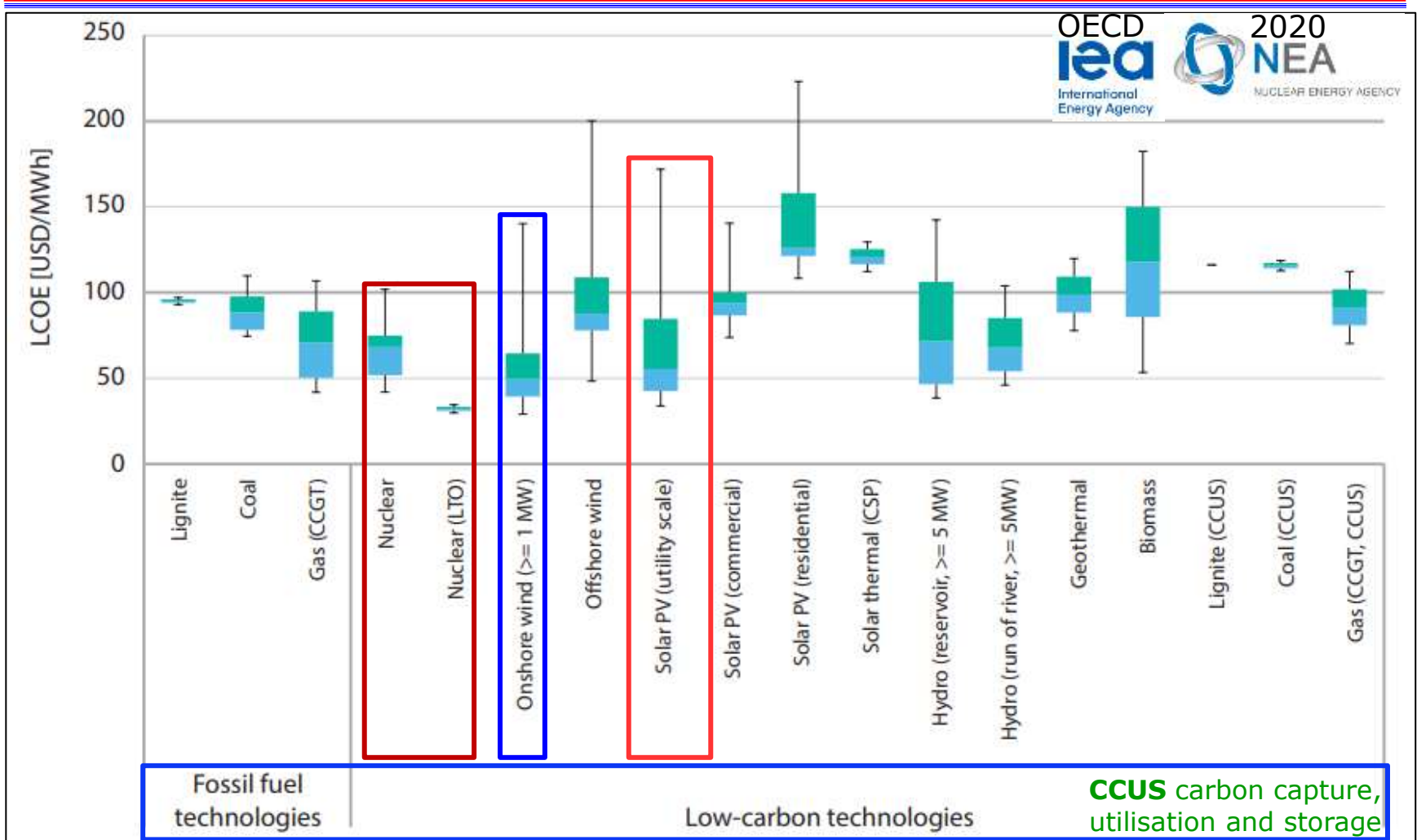
Instrumentation Civil Works,..)

**Discount Rate:**  
 a) financing cost  
 b) perceived risk  
 c) inflation

~\$0.03/kWh

Overnight LTO investment costs (USD/kWe)	LWR LTO LCOE (USD/MWh)					
	10 years			20 years		
	Discount rate			Discount rate		
	3%	7%	10%	3%	7%	10%
	Capacity factor = 85%					
450	29.4	31.2	32.6	26.4	28.6	29.7
700	33.4	36.1	38.3	28.7	31.4	33.8
950	37.4	41.1	44.1	31.0	34.7	38.0

# Levelized Cost of Electricity (2020)



Note: Values at 7% discount rate. Box plots indicate maximum, median and minimum values. The boxes indicate the central 50% of values, i.e. the second and the third quartile.

# LCOE Nuclear vs. Fossil-Fuel Power in US/EU

Carbon Tax	Natural Gas		Coal		Nuclear
	LCOE	LCOE with Carbon Cost <sup>a</sup>	LCOE	LCOE with Carbon Cost	LWR
US	0.67	0.85	0.88	1.21	1.0
South Korea	1.54-2.69	1.78-2.93	1.40	1.99	1.0
Japan	0.92-1.46	1.05-1.58	0.94	1.23	1.0
China	0.74-1.72	0.97-1.95	1.03	1.63	1.0
France	0.58-1.05	0.71-1.18	-	-	1.0

<sup>a</sup> Assumed carbon cost is \$30/tonne of CO<sub>2</sub>

- Currently: New NPP not profitable investment in US and EU.
  - Capital on-site construction costs too high (→modern modular, factory).
- Cost not dominated by reactor and turbine islands but by
  - civil works, structures and buildings, electrical installation; associated indirect costs for this work on site.
- Cost reductions and/or revenue enhancement accomplished by
  - standardizing design, modus of reactor construction (prefab, modular), reduced commodity use, incorporating modern fabrication/construction technologies from other fields applicable to nuclear power.

MIT Report: The future of Nuclear Power in a Carbon-Constrained World

# Conclusion: Nuclear Power in a Sustainable Future (?)

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Western Gen III plants have good safety record (safest dispatchable energy). But 3 *preventable* accidents with core damage ("melt down"), 1 accident fatal, temporary evacuation.

Gen III, III+ proven/mature technologies (PWR, U based), breeder reactors

## **To develop and employ advanced nuclear power in the U.S.:**

- Continue to improve the safety of nuclear reactors and processing plants.
- Test/construct advanced modular nuclear reactors @ sites of existing plants.
- Test/construct advanced burner/transmuter → reduce radiotoxic waste.
- Import/develop closed nuclear fuel cycle technologies.
- Develop/test proliferation-safe reprocessing methods (e.g., UREX+).
- **Further test/develop a closed Th/U breeder fuel cycle.**
- Develop ADS systems, high current accelerator technology.
- Develop the material chemistry of molten salt mixtures, molten salt reactor.
- Expand the radio-chemistry of actinides, transactinides and fission products.
- **Operating a semi-permanent nuclear waste depository, flexible strategy.**
- **Train personnel in nuclear and radiation technologies !**